Performance of the Accelerator Complex

CDF TEV Fest

July 26, 2004

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Outline

- Goals
- Performance
- Major Accomplishments
- Machine Issues
- FY05 Outlook
- Future Predictions

Goals

Major FY04 Goals

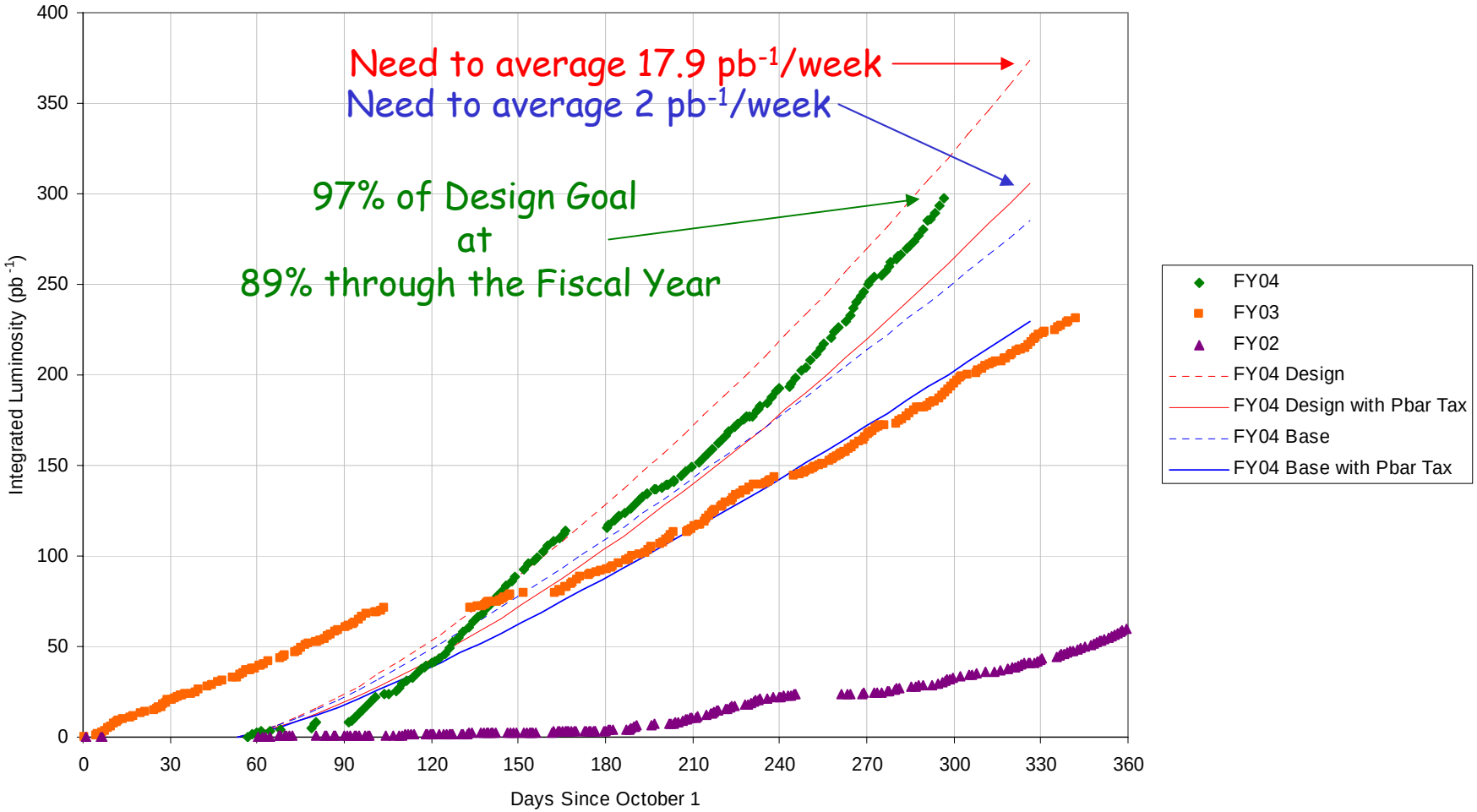
- Operate the Collider at the Main Injector project luminosity design goals
  - 80% Antiproton transform efficiency from the Accumulator to Low Beta
  - 260×10^{9} protons per bunch
  - 18×10^{10}/hour antiproton zero stack stacking rate
  - Peak Luminosity of $80 \times 10^{30} cm^{-2} sec^{-1}$
- Integrate over $300 pb^{-1}$ in 39 weeks
- Prepare the Collider for implementation of the initial stages of the Run II Upgrades
  - Slip Stacking
  - AP2-Debuncher Aperture
- Commission the Recycler for electron cooling

FY04 Performance

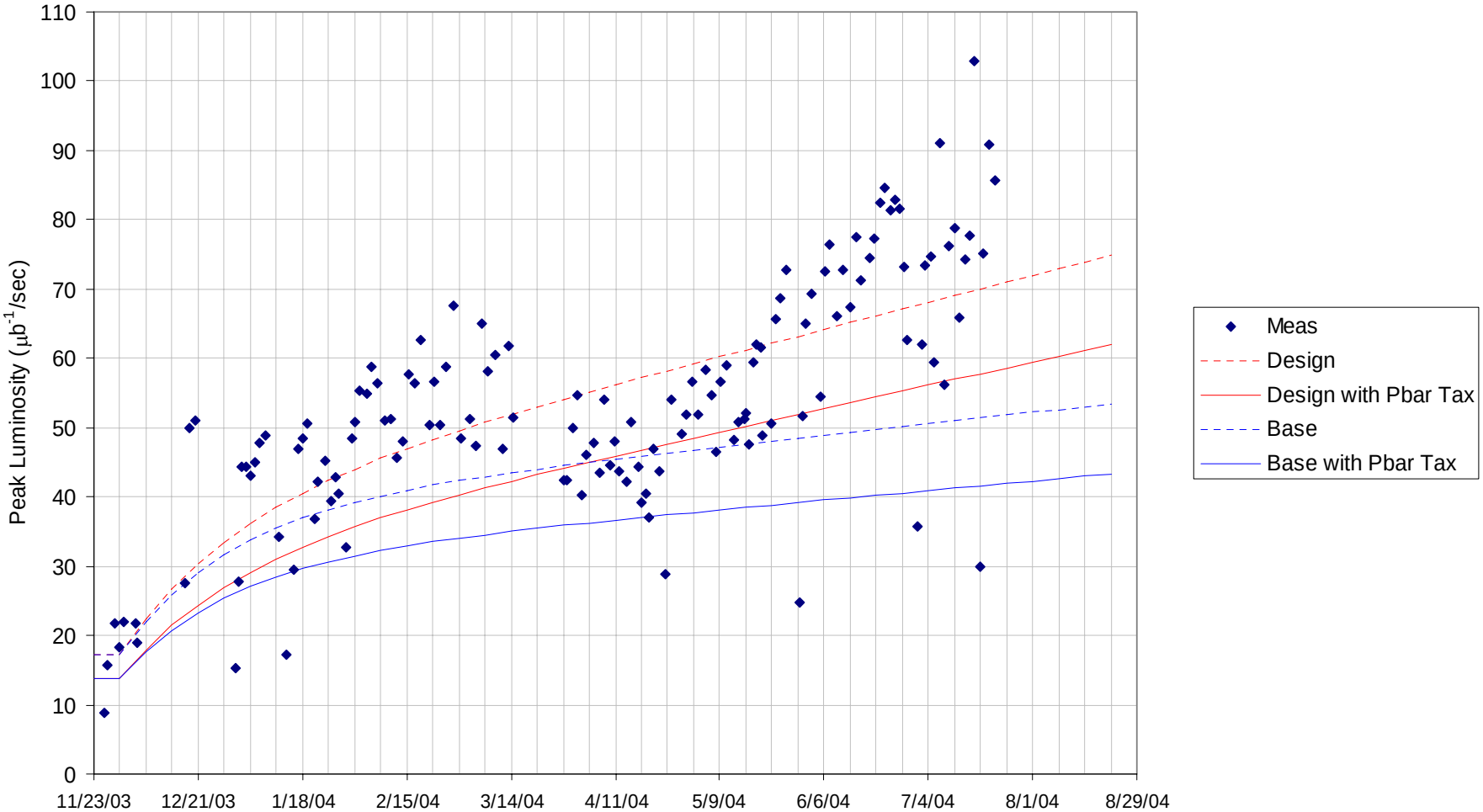
Comparison Between FY03 and FY04

- Integrated Luminosity
  - FY03 240 pb^{-1} in 44 weeks
  - FY04 ~350 pb^{-1} in 39 weeks
- Average Weekly Integrated Luminosity at fiscal year end
  - FY03 6.4 pb^{-1}
  - FY04 14.3 pb^{-1} (with best at 18 pb^{-1})
- Average Peak Luminosity at fiscal year end
  - FY03 $36.1 \times 10^{30} cm^{-2} sec^{-1}$
  - FY04 $75.7 \times 10^{30} cm^{-2} sec^{-1}$
- Best Peak Luminosity
  - FY03 $48 \times 10^{30} cm^{-2} sec^{-1}$
  - FY04 $103 \times 10^{30} cm^{-2} sec^{-1}$

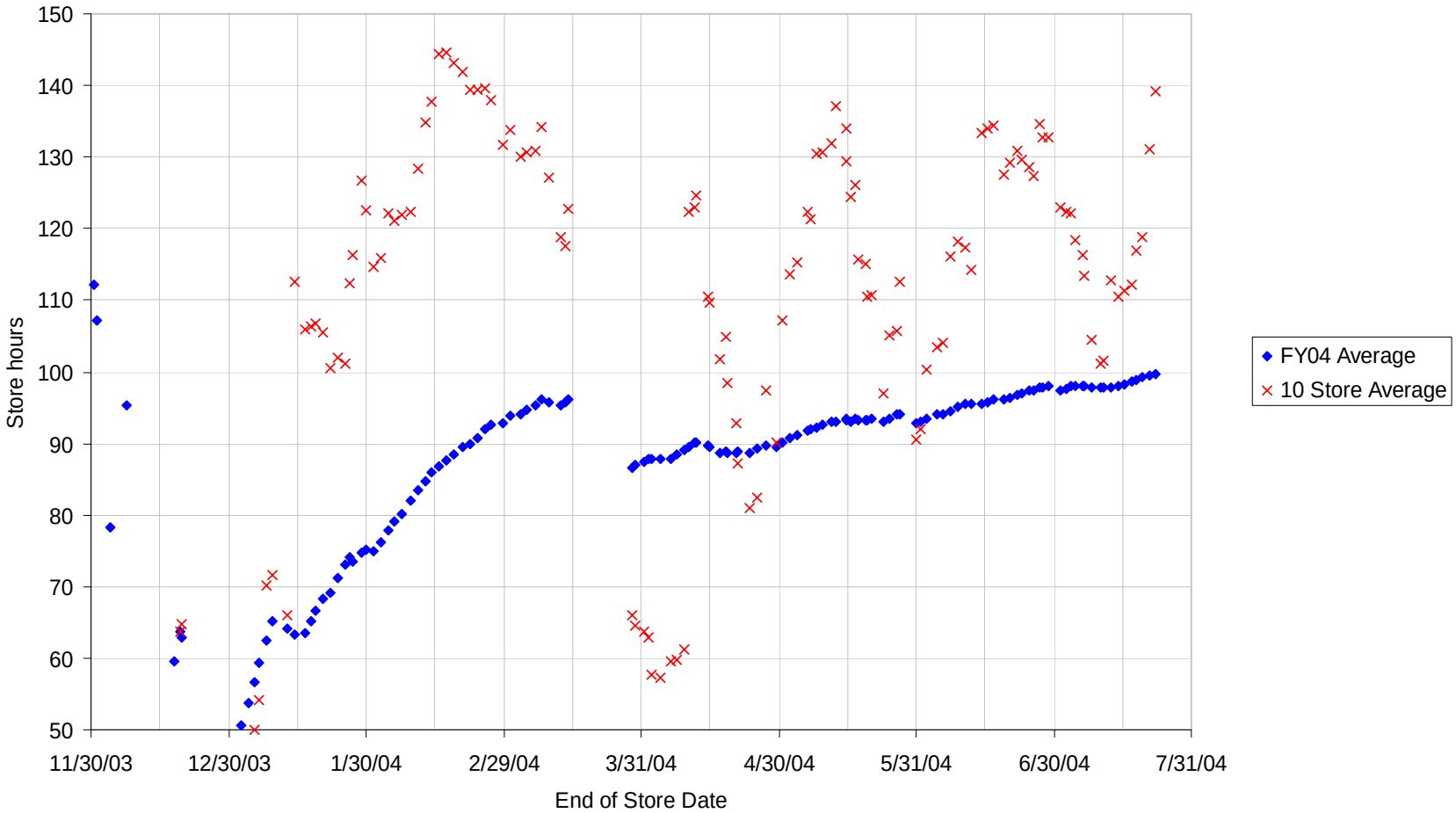
Integrated Luminosity



FY04 Peak Luminosity



FY04 Average Store Hours per Week



Data Summary Table

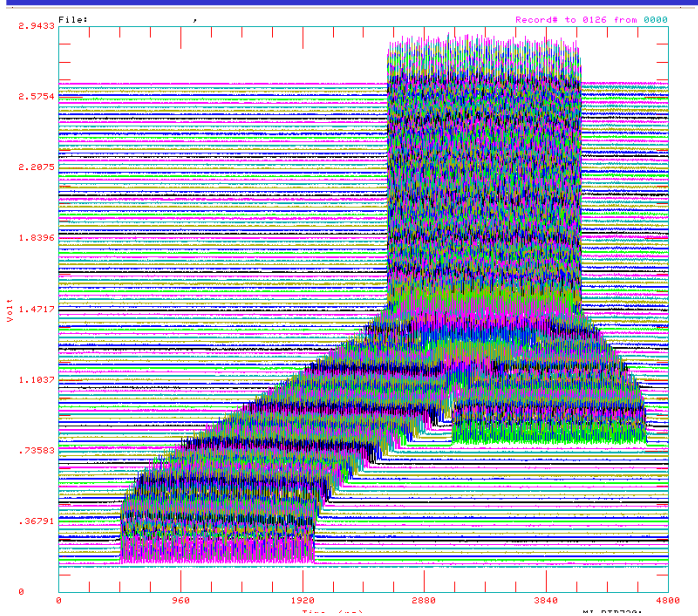
				Store Parameters					
Parameter	Last Store	Best Store	Last 10 stores Average	Best 10 stores Average	FY04 Average	End of FY03	FY04 (End) Design	FY04 (End) Base	
Initial Luminosity (Average)	85.8	102.8	75.7	84.1	52.8	36.1	61.9	43.3	$x10^{30}cm^{-2}sec^{-1}$
Integrated Luminosity per Store (Averaged)	3528	4241	2672	2827	2041	1089	2000	1300	nb^{-1}
Luminosity per week (Averaged)	-	-	14.3	-	8.4	6.4	11.3	7.4	pb^{-1}
Store Length	29.9	32.4	25.1	23.3	24.4	14.9	15.0	15.0	Hours
Store Hours per week	-	-	133	-	100	88	85	84	Hours
Shot Setup Time	2.2	2.4	2.5	2.5	2.5	2.3	2.2	2.2	Hours
				TEVATRON Parameters					
Parameter	Last Store	Best Store	Last 10 stores Average	Best 10 stores Average	FY04 Average	End of FY03	FY04 (End) Design	FY04 (End) Base	
Protons per bunch	250	246	250	250	235	237	260	260	$x10^{9}$
Antiprotons per bunch	37	43	32	35	27	22	31	25	$x10^{9}$
Proton Efficiency to Low Beta	74	85	81	78	76	58	-	-	%
Pbar Transfer efficiency to Low Beta	90	86	75	75	73	63	80	77	%
HourGlass Factor	0.68	0.66	0.69	0.68	0.68	0.70	0.65	0.65	
Initial Luminosity Lifetime	6.2	5.2	6.8	6.2	7.8	9.5	8.3	7.0	hours
Asymptotic Luminosity Lifetime	18.4	17.7	19.3	20.3	23.6	25.1	25.0	25.0	hours
Effective Emittance	18.2	16.9	18.7	17.4	18.5	21.6	21.0	23.0	π-mm-mrad
				Antiproton Parameters					
Parameter	Last Store	Best Store	Last 10 stores Average	Best 10 stores Average	FY04 Average	End of FY03	FY04 (End) Design	FY04 (End) Base	
Zero Stack Stack Rate	13.3	13.2	12.2	12.8	11.4	11.5	18.0	13.7	$x10^{10}$/hour
Normalized Zero Stack Stack Rate	2.5	2.5	2.3	2.4	2.3	2.3	3.6	2.7	$x10^{-2}$/hour
Average Stacking Rate	5.0	6.8	6.6	6.8	5.8	7.1	9.3	7.6	$x10^{10}$/hour
Stacking Time Line Factor	54	86	79	86	78	88	75	75	%
Stack Size at Zero Stack Rate	361	309	364	306	296	300	300	300	$x10^{10}$
Protons on Target	5.0	5.3	5.3	5.3	5.0	5.0	5.0	5.0	$x10^{12}$
Start Stack	162	198	172	186	155	144	155	130	$x10^{10}$
End Stack	11	17	16	17	21	16	15	15	$x10^{10}$
Unstacked Pbars	150	181	156	169	135	128	140	115	$x10^{10}$

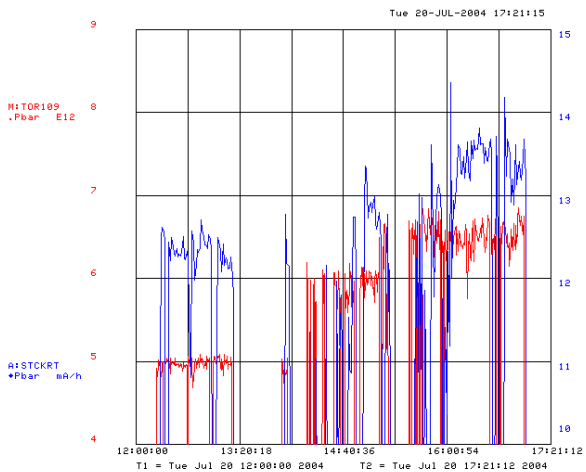
Major Accomplishments

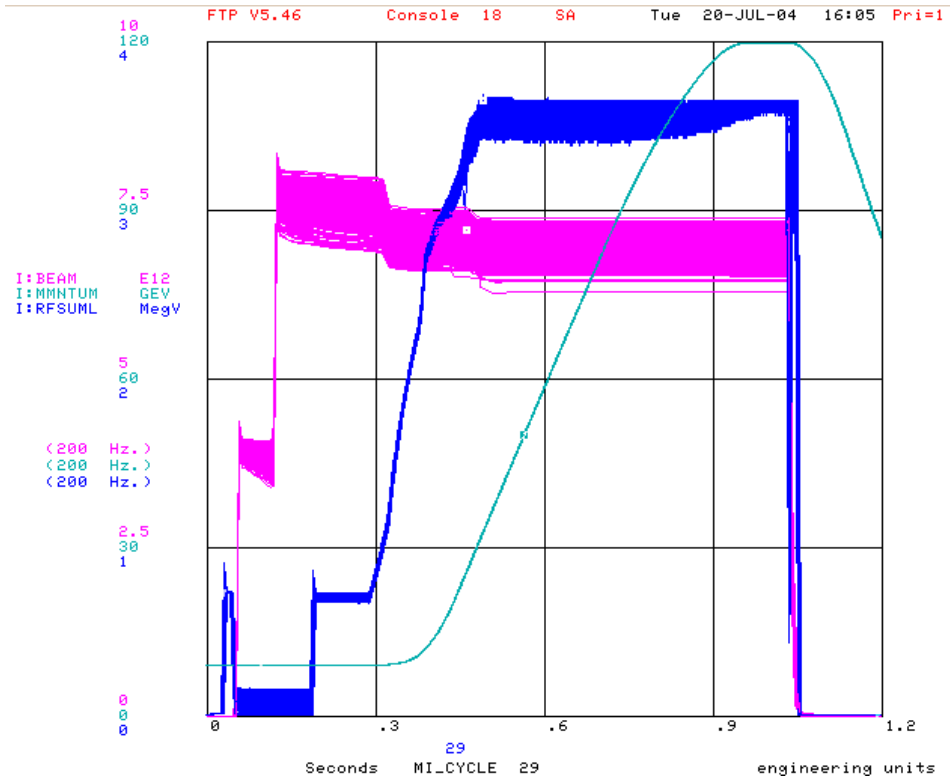
Major Accomplishments for the Collider in FY04

- Proton Source
  - Record intensities- 6.0×10^{12} protons/pulse for stacking
  - Record efficiencies > 85%
  - Record throughput > 1.0×10^{19} protons/week for Miniboone
- Main Injector
  - Bunch Length reduction from dampers and beam loading compensation
    - 20% for coalescing
    - 50% for stacking
  - 2.5 MHz transfers – 95% pbar coalescing efficiency
  - Slip Stacking for Pbar Stacking

Slip Stacking







Tevatron Major Accomplishments

- Tevatron
  - Alignment
    - Projects
      - Tev-Net
      - Smart bolt retro-fit
      - Dipole Un-Rolls
      - P1 Line roll
      - IP low-beta regions
      - Tight aperture areas
    - Results
      - Better injection efficiency
      - Smaller emittance at collisions
      - Better ramp efficiency
      - Better store-store reproducibility
  - 4 mm vertical move of beam position at CDF IP
  - New Low Beta optics (April 04 – June 04)
    - 20-30% increase in luminosity
    - Smaller beta*
    - Smaller emittance

Major Accomplishments

- Recycler
  - At the end of FY03
    - The Recycler was "on the ropes"
      - Lifetime was < 60hrs
      - Transverse emittance growth was 12π-mm-mrad/hr
    - Took drastic measures
      - Re-organized the department (broke it away from Main Injector)
      - Lengthened the Fall 03 shutdown to bake the entire Recycler
      - Instituted the Pbar Tax (Investment) to guarantee the Recycler adequate study time and access to the tunnel
      - Re-organized the Accelerator Physics Dept. to give the Recycler and Tevatron more accelerator physicists
  - Recycler bake-out was extremely successful
    - Transverse emittance growth reduced by a factor of 5-8
    - Lifetime > 300 hours
  - Recycler commissioning has progressed rapidly
    - Stand alone Recycler shots to the Tevatron (Jan. '04)
      - Initial Luminosity > $17 \times 10^{30} cm^{-2} sec^{-1}$
      - Integrated useable luminosity
    - Stack of $>150 \times 10^{10}$ pbars in the Recycler
  - Using the Recycler in Mixed Pbar operations makes it a luminosity enhancement
    - The top 3 luminosity stores were done with using the Recycler
  - Recycler is ready for Electron Cooling

Major Accomplishments

- Operations
  - Long Stores
    - More integrated luminosity
    - More reliability - minimize ramping & shot setup
    - Better able to integrate machine studies
  - Better Planning
    - Permanent run coordinator (Jim Morgan)
    - Daily 9 am operations meetings
    - Focused control of machine studies
      - Integrate luminosity when the machine is running well
      - Do machine studies when the machine is behaving poorly
  - Mixed Pbar Operation
    - Proposed in February '04 by Brian Chase
    - Initial proposal presented at the April '04 Run II PMG
    - Dual energy ramps in the MI completed and tested by May '04
    - First Attempt 6/13/04
    - Record Luminosity of $103 \times 10^{30} cm^{-2} sec^{-1}$ recorded 7/16/04

Mixed Pbar Extraction

- Extracting pbars from both the Accumulator and the Recycler for the same store i.e.
  - Twenty four bunches from the Accumulator
  - Twelve bunches from the Recycler
- Reasons
  - Flexibility in the Run II Upgrade schedule
    - Natural merging of commissioning of electron cooling
  - Push Recycler commissioning progress by plunging it into operations
  - Luminosity enhancement – larger amount of pbars for smaller emittances
    - Accumulator stack size limited to <200 mA
      - Stacking Rate
      - Transverse emittance vs Stack Size
- Ratio $I_{Recycler}/I_{Accumulator}$ is governed by:
  - Recycler phase space density (cooling)
  - Recycler transfer time (Rapid transfers)
- Obstacles
  - Stacking Rate
  - Injector Complex 8 GeV energy alignment
  - Longitudinal emittance in both the Accumulator and Recycler
  - Transfer time between Accumulator to Recycler

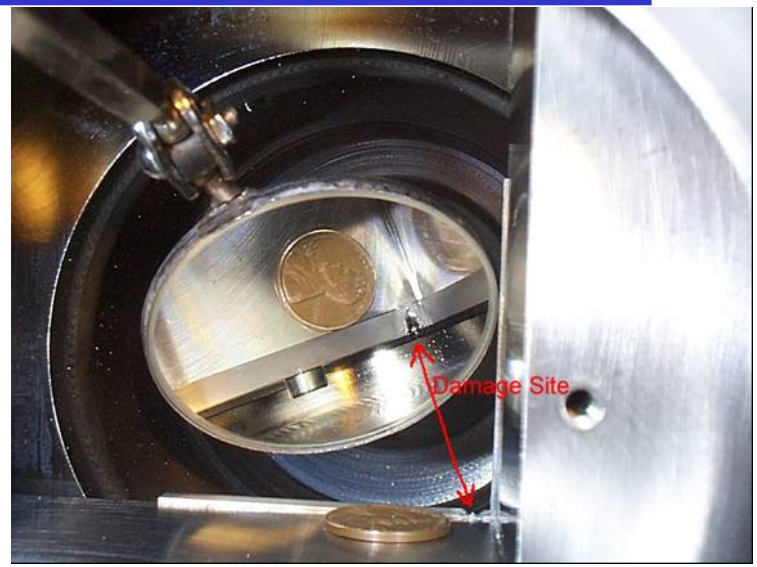
Machine Issues

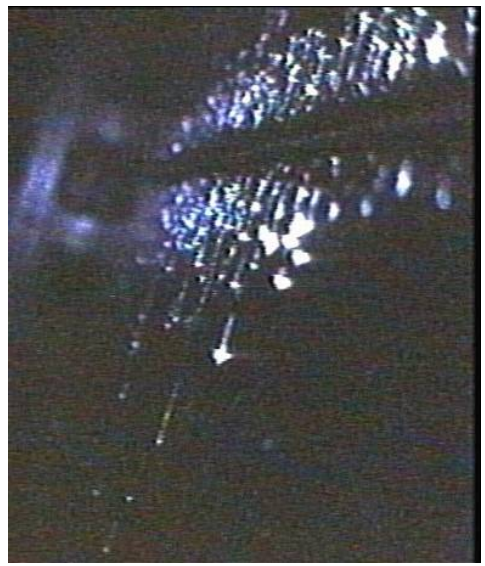
Machine Issues

- Pbar Production
  - Goal for this year was 18×10^{10} pbars/hr
  - We are at 13.5×10^{10} pbars/hr
  - We have finished an extensive pbar plan that has checked and/or upgraded almost all of the cooling systems in the Antiproton Source
    - The present systems in their current configuration should be able to handle a flux of 29×10^{10} pbars/hr
  - We have recently narrowed the problem down to an measurements that imply an extremely small aperture in the transfer line between the Debuncher to Accumulator
    - Direct measurements are very difficult because of the very small amount of pbars transmitted through this line
    - We have developed a study plan to understand this aperture problem which should be completed by the end of FY04
    - If we can increase the aperture of this transfer line to the design value, there should be little problem in achieving 18×10^{10} pbars/hr

Machine Issues

- TEVATRON
  - TEV Abort
    - Unmasking of inputs for protection
    - New BLM system as abort input
    - Kicker Pre-fires
      - Collimator design
      - Abort block reconfiguration





FY05 Outlook

Plans for FY05

- Install electron cooling in the Recycler in Fall '04 shutdown
- Run Slip Stacking at 8×10^{12} protons/pulse every 2 secs
- Increase the pbar production aperture by 25%
- Stack at small stacks with a rate of 26×10^{10} pbars/hr
- Run the complex in Mixed Pbar operations
  - Assume the gain from Mixed Pbar operations is "break-even" (pessimistic?)
- Commission electron cooling for operations by the end of FY05

DRAFT FY05 Goals

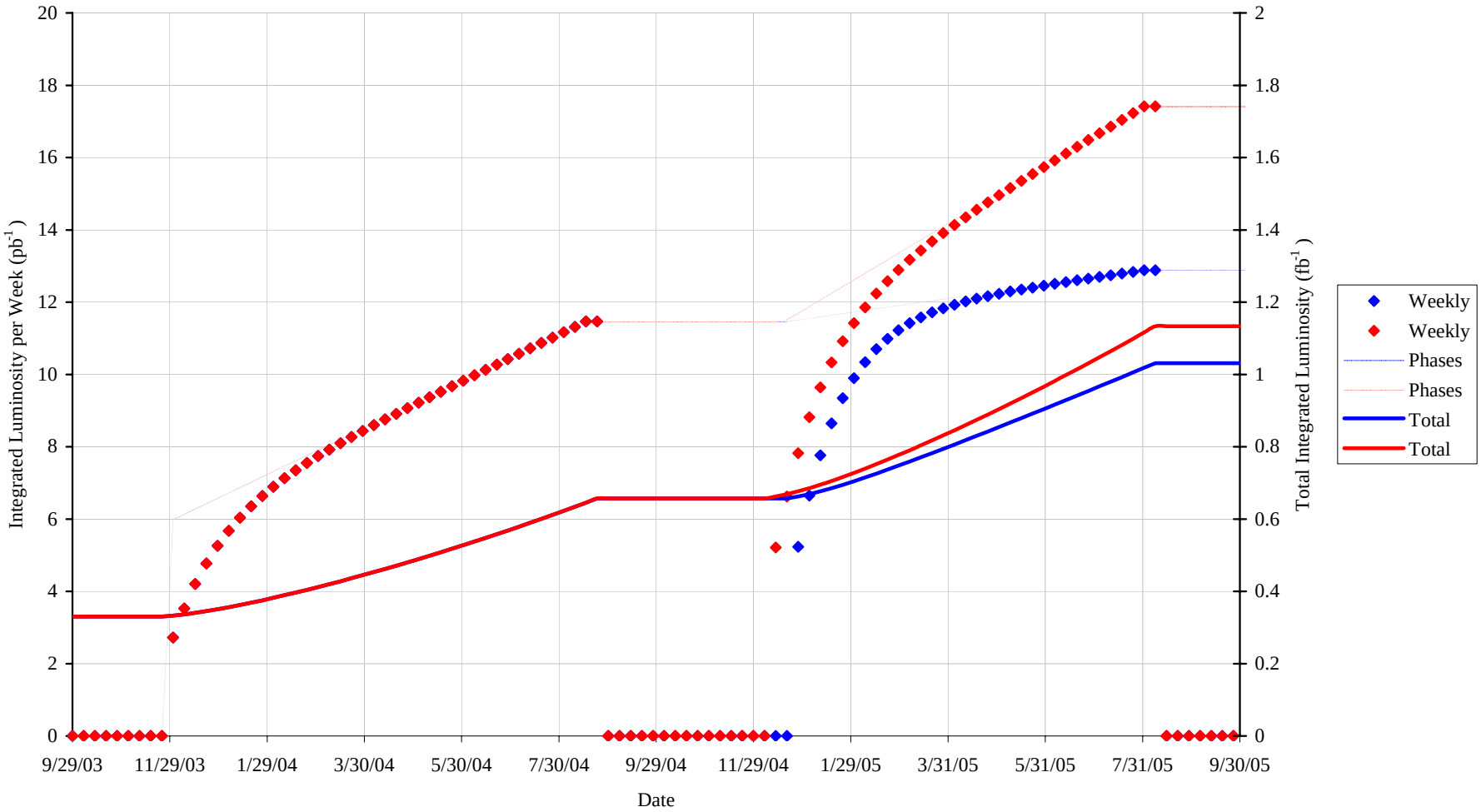
Luminosity Parameters				
Phase	1	Design	Base	
Initial Luminosity	72.8	99.3	77.6	$x10^{30}cm^{-2}$
Average Luminosity	32.0	48.4	37.8	$x10^{30}cm^{-2}$
Integrated Luminosity per week	11.5	17.4	12.9	pb^{-1}
Integrated Luminosity per store	2.9	3.5	2.7	pb^{-1}
Number of stores per week	4.0	5.0	4.7	
Average Store Hours per Week	100	100	95	Hours
Store Length	25	20	20	Hours
Initial Lifetime	6.4	6.4	6.4	Hours
Average Lifetime	12.8	12.0	12.0	Hours
HEP Up Time per Week	110	113	107	Hours
Shot Setup Time	2.6	2.6	2.6	Hours
	FY04 Plan	Slip Stacking	Slip Stacking	

TEVATRON Parameters				
Phase	1	Design	Base	
Number of Protons per bunch	250	260	260	$x10^{9}$
Number of Pbars per bunch	31.6	43.9	34.3	$x10^{9}$
Proton Emittance	24	25	25	π-mm-mra
Pbar Emittance	11	12	12	π-mm-mra
σ_{proton}	0.500	0.500	0.500	cm
σ_{pbar}	0.500	0.500	0.500	cm
BetaIP	35	35	35	cm
Transfer Eff. To Low Beta	0.72	0.76	0.75	
	FY04 Plan	Slip Stacking	Slip Stacking	

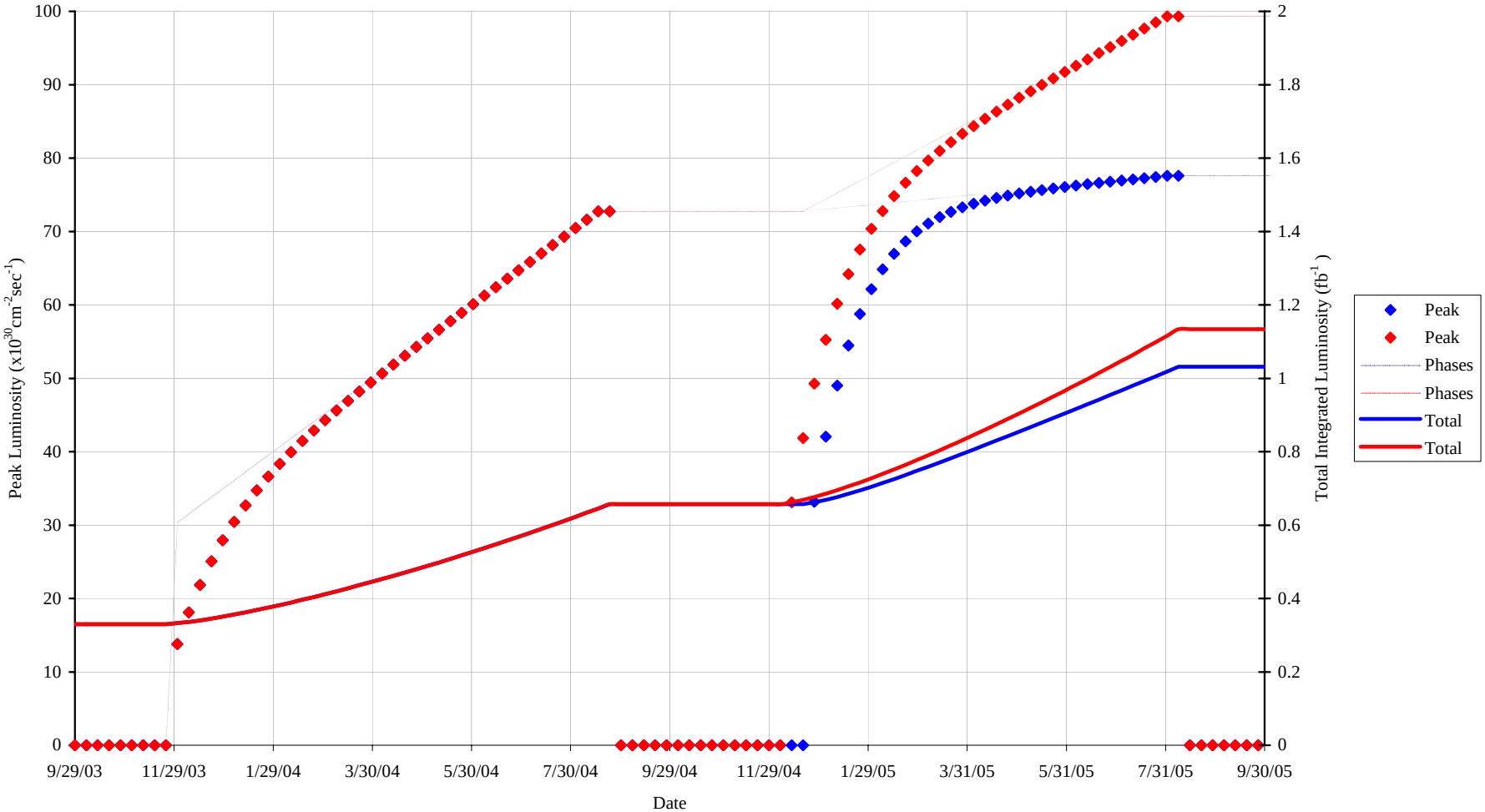
Antiproton Parameters				
Phase	1	Design	Base	
Zero Stack Stacking Rate	13.0	26.2	17.2	$x10^{10}$/hou
Average Stacking Rate	6.3	10.4	8.2	$x10^{10}$/hou
Stack Size transferred	158.2	208.0	164.7	$x10^{10}$
Stack to Low Beta	113.9	158.1	123.5	$x10^{10}$
Pbar Production	16.0	20.0	17.0	$x10^{-6}$
Protons on Target	5.4	8	6.2	$x10^{12}$
Pbar cycle time	2.4	2.2	2.2	Secs.
Pbar up time fraction	0.75	0.75	0.75	
Initial Stack Size	15	15	15	$x10^{10}$
Stack Size at 1/2 Stacking Rate	150	150	150	$x10^{10}$

Fiscal Year	Accumulated	Accumulated	per Year	per Year
	fb^{-1}	fb^{-1}	fb^{-1}	fb^{-1}
FY03	0.33	0.33	0.33	0.33
FY04	0.66	0.66	0.33	0.33
FY05	1.13	1.03	0.48	0.37

DRAFT FY05 Goals Integrated Luminosity



DRAFT FY05 Goals Peak Luminosity



Future Predictions

Completely Irresponsible Predictions for the Future

- Predictions:
  - If we can:
    - stack > 26×10^{10} pbars/hour at small stacks
    - Use the Recycler in Mixed-Pbar operation
  - obtaining:
    - 4 fb^{-1} by the end of FY09 should be a "slam-dunk"
    - 8 fb^{-1} by the end of FY09 could be possible
  - If:
    - Electron cooling works in the Recycler
    - stack > 30×10^{10} pbars/hour at small stacks in the Accumulator
  - obtaining > 8 fb^{-1} by the end of FY09 should be straight-forward
- FY05 will be a pivotal year for the Run II Collider
  - Pbar stacking
  - Mixed Pbar operation
  - Electron cooling installation and commissioning